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A Tri-State Optical Switch for Local Area Network Communications

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Abstract: This novel structure is a heterojunction phototransistor which can be used as an emitter-detector, and when placed in a quiescent mode, the device becomes a passive transmitter. By varying the voltage bias, this novel device will switch between all three modes of operation. Such a device has broad application in network environments with operation speeds of less than 50MHz and distances of less than 1km, e.g. automobiles, airplanes, and intra-instrumentation [7]. During this period, the emission mode for this device was studied and mathematically modeled.

Introduction

Shown in Fig. 1, the device is a heterojunction phototransistor. It consists of four epitaxial layers grown on a semiconducting substrate. A buffer can be grown to insure layer quality. Essentially, this device has a bipolar transistor configuration in which region (A) contains the emitter, region (B) is the base, and region (C) is the collector.

Typically, emission and detection are not embodied in the same device because of low detection response. Therefore, a key feature to the implementation of this structure is the Franz-Keldysh effect [3,7]. By placing a high electric field across the depletion width, approximately 10^4 V/cm, a small shift in the absorption edge occurs as shown in Fig. 2. Because of the absorption characteristics in GaAs, a small shift induces a large change in the absorption coefficient. Thus, by modulating an applied voltage to the device, the absorption coefficient is increased or decreased. Thereby, the device is altered from a detecting state to a passive state. (A slight pre-bias may be applied to improve the switching times.)

The emission mode of the device occurs by placing a forward bias across the emitter junction. The resulting emission characteristics are shown in Fig. 3. In general, the emission pattern is non-coherent and is characterized as Lambertian. A portion of the light is transmitted perpendicularly through the top of the device, and other components are confined and transmitted laterally towards the edges of the device. The following is a mathematical model for that emission.

Mathematical Description

The method of analysis used was similar to that for a cylindrical waveguide with an active cladding [2,5,8]. The similarities exist in that both have a Lambertian source distribution within the waveguide. Also, light can undergo total internal reflection and be transmitted laterally through the waveguide as shown in Fig. 4. As a result, Maxwell's equations will include a source term (J) which significantly complicates their solutions.

The two main equations are

$$\nabla\times \mathbf{E} = i\sqrt{\frac{\mu_o}{\varepsilon_o}}\, k\mathbf{H} \quad (1)$$

$$\nabla\times \mathbf{H} = \mathbf{J} - i\sqrt{\frac{\varepsilon_o}{\mu_o}}\, kn^2\, \mathbf{H} \quad (2)$$

and for an unpolarized source in a non-magnetic material

$$\mathbf{J} = \sigma \mathbf{E} \quad (3)$$

where σ is the conductivity, k is the wavenumber, and n is the index of refraction. Also, we can assume that the electric field (**E**) and magnetic field (**H**) can be written as

$$\mathbf{E} = \mathbf{e}(x,y)\, e^{-i\beta z}\, e^{i\omega t} \quad (4)$$

$$\mathbf{H} = \mathbf{h}(x,y)\, e^{-i\beta z}\, e^{i\omega t} \quad (5)$$

and

$$\mathbf{e}(x,y) = \mathbf{e}_t + e_z \quad (6)$$

$$\mathbf{h}(x,y) = \mathbf{h}_t + h_z \quad (7)$$

where the fields can be separated into a transverse (t) and longitudinal component ($\hat{z}$) [8]. We have been able to derive the **e** and **h** fields for the emission mode of the tri-state switch as

$$\mathbf{e}_t = \frac{\frac{i}{k}\sqrt{\frac{\varepsilon_o}{\mu_o}}}{\frac{1}{k}\sqrt{\frac{\varepsilon_o}{\mu_o}}\left(k^2 n_2^2 - \beta^2\right) + i\sigma}\left[\beta \nabla_t h_z - k\sqrt{\frac{\varepsilon_o}{\mu_o}}\,\hat{z} \times \nabla_t h_z\right] \quad (8)$$

$$\mathbf{h}_t = \frac{\frac{i}{k}\sqrt{\frac{\varepsilon_o}{\mu_o}}}{\frac{1}{k}\sqrt{\frac{\varepsilon_o}{\mu_o}}\left(k^2 n_2^2 - \beta^2\right) + i\sigma}\left[\beta \nabla_t h_z + k n_2^2\sqrt{\frac{\varepsilon_o}{\mu_o}}\,\hat{z} \times \nabla_t e_z + i\sigma \hat{z} \times \nabla_t e_z\right] \quad (9)$$

note that both expressions are a function of only the longitudinal components. Therefore, by deriving the longitudinal expressions e_z and h_z , we can fully describe the wave propagation within the diode.

By solving the homogeneous part of Maxwell's equation [2,3,9,10]

$$\nabla^2 \mathbf{E} = -k^2 n^2\, \mathbf{E} \quad (10)$$

in which $\frac{\partial}{\partial y} \neq 0$, we can derive a relationship for the components in the three regions of the waveguide

$$e_z = \begin{cases} [C_1 \cos(\gamma y) + C_2 \sin(\gamma y)]\, C_6 e^{-Lx} & x \geq t_g \\ [C_1 \cos(\gamma y) + C_2 \sin(\gamma y)]\,(C_3 \cos(mx) + C_4 \sin(mx)) & 0 \leq x \leq t_g \\ [C_1 \cos(\gamma y) + C_2 \sin(\gamma y)]\, C_5 e^{Lx} & x \leq 0 \end{cases} \quad (11)$$

where

$$m = \sqrt{p^2 - \gamma^2} \quad (12)$$

$$L = \sqrt{q^2 + \gamma^2} \quad (13)$$

$$p = \sqrt{k^2 n_2^2 - \beta^2} \quad (14)$$

and

$$p = \sqrt{\beta^2 - k^2 n^2} \quad (15)$$

where n_{outer} represents the index of refraction in regions (A) and (C), and γ is a constant related to the type of mode and mode number. (A similar expression for is expected.) By imposing the conditions of continuity at the interface $C_3 = C_5 = \frac{m}{L} C_4$, and a transcendental equation in β, the propagation constant, is derived

$$\mathrm{Tan}\left(mt_g\right) = \frac{2mL}{m^2 - L^2} \quad (16)$$

to which a solution has not yet been obtained.

Conclusion

The emission mode of this novel structure has been partly modeled. A solution to the transcendental equation remains. The approach leading to this solution has not been typically used to describe semiconductor waveguides. However, in each case, the equations collapse to established forms for the source free condition [1,4,8]. Thus, by substitution of e_z and h_z into equations (8) and (9), the wave propagation within the tri-state switch is completely described.

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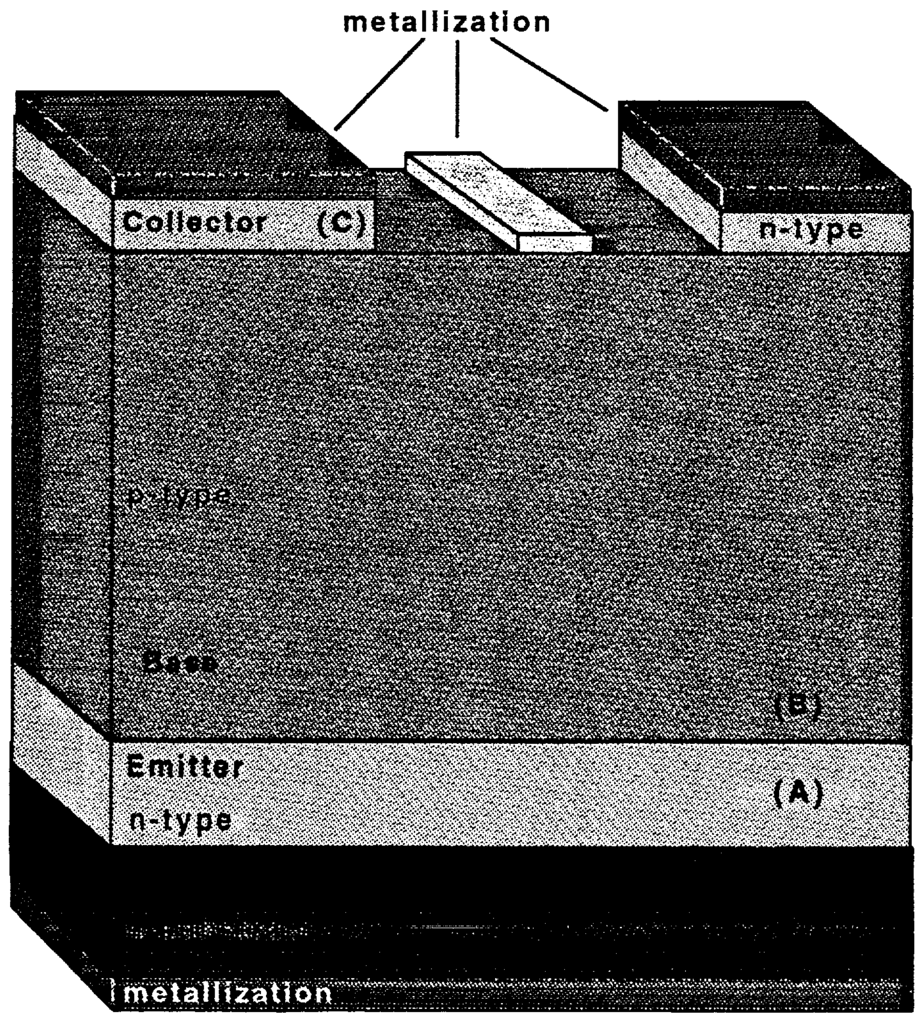


Figure 1: The tri-state optical switch. A heterojunction phototransistor consisting of four epitaxial layers. The diode is represented in a bipolar junction configuration.

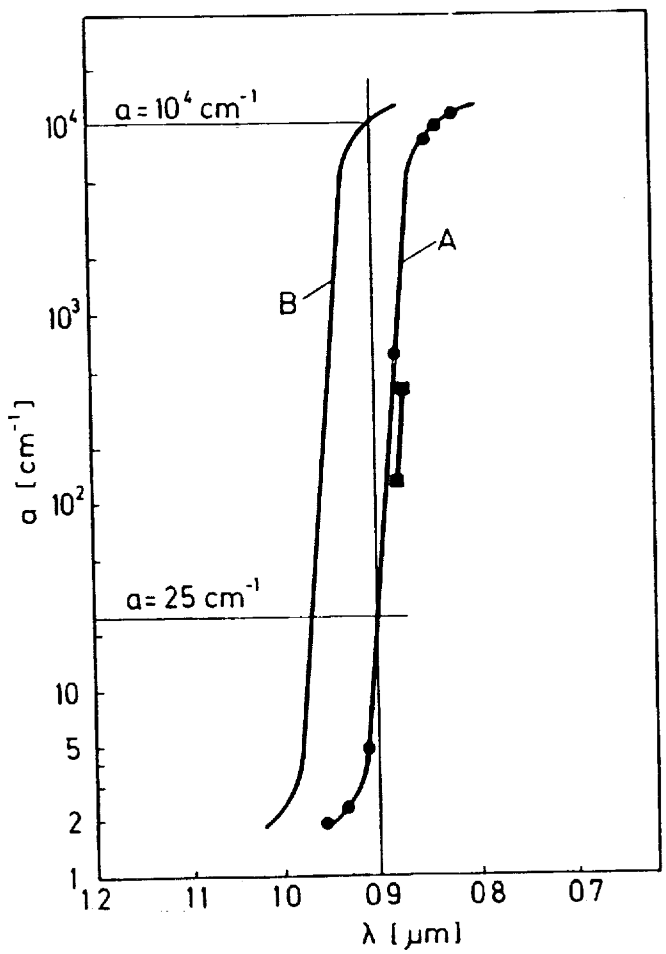


Figure 2: The Franz-Keldysh effect in GaAs. At zero bias, the absorption coefficient α=25cm^{-1}. When a high electric field is applied, the absorption coefficient shifts to α=10^4cm^{-1}.

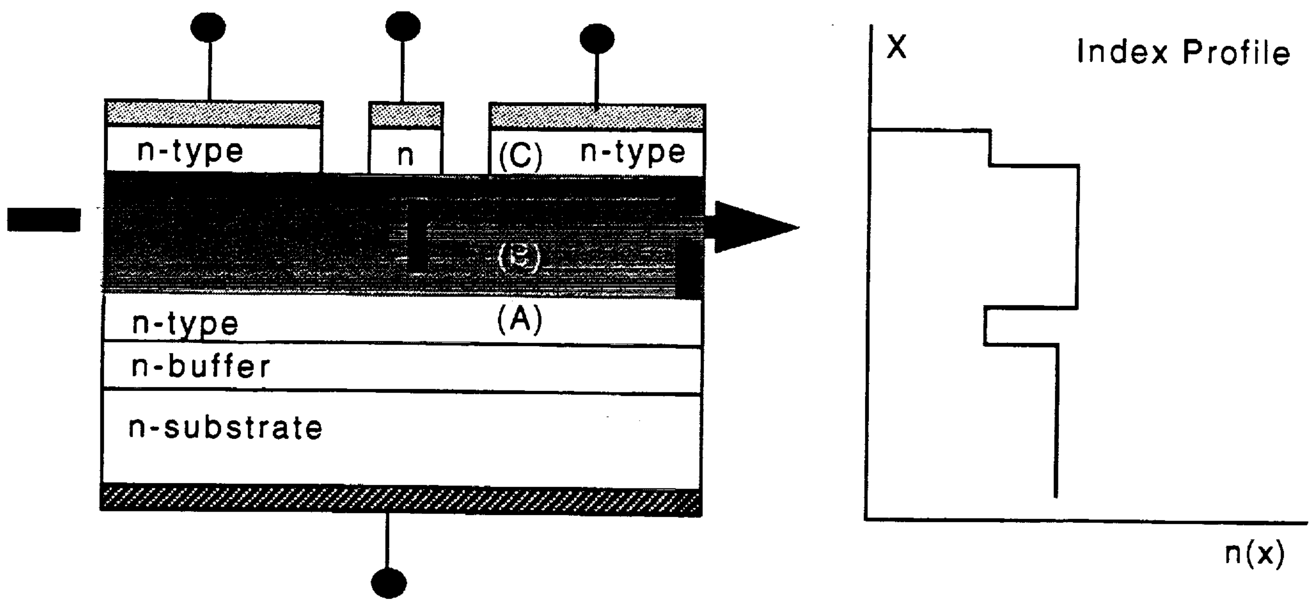
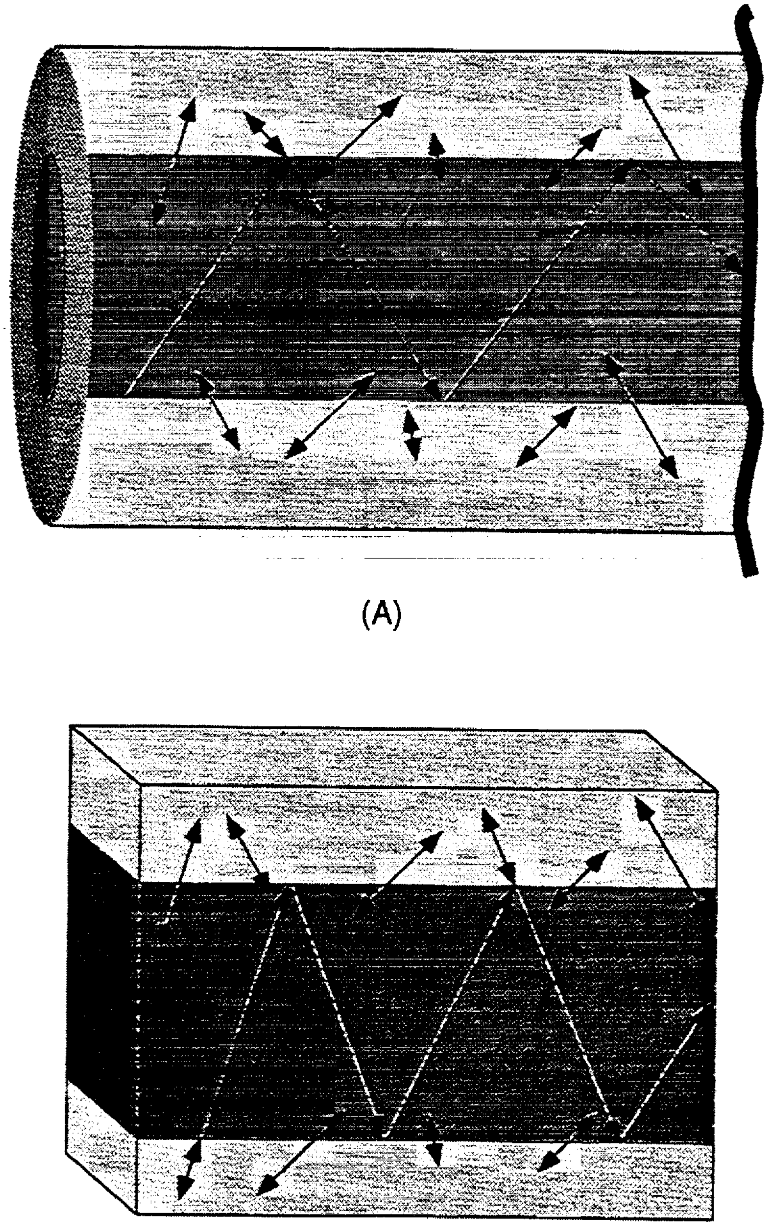


Figure 3: Shown above is the emission pattern that occurs at the emitter junction of the tri-state switch. Light is emitted equally in all directions. Some of the light is confined and channeled towards the edge of the device. The confinement is a result of the variation in the index of refraction.



(A)

(B)

Figure 4: (A) A cylindrical waveguide in which the interface/cladding region is active. Light is coupled into the core and emitted through the distal and proximal ends of the fiber. (B) A rectangular waveguide in which a source is located at one of the interfaces. Likewise, light is coupled into the core and transmitted laterally.

A STUDY OF SPACE STATION FREEDOM REDESIGN AND VARIOUS EARTH OBSERVING SATELLITE SYSTEMS

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As a brief acknowledgment, I express my appreciation to the NASA/ASEE Summer Faculty Fellowship Program and to Dr. Roger Breckenridge, Assistant Chief of the Advanced Space Concepts Division (ASCD) for the opportunity of spending an enjoyable, productive, and rewarding summer studying Langley Research Center's (LaRC) role in the redesign of the Space Station Freedom and in the process of choosing payload and satellite configuration for various past, present, and future Earth observing missions. The NASA/ASEE Fellowship gave me access to the publication and materials from the ASCD and the LaRC Technical Library as well as to the expertise of the scientists and engineers of the Center. The information acquired in the study will be integrated into an honor course entitled "Space Exploration," which I teach at The University of South Carolina-Coastal Carolina College.

At the time of this writing, three options (A-1, B, C) and one variation on an option (A-2) have been given to President Clinton by the Space Station Redesign team. Options A-1 and C have been eliminated, while options A-2 and B are still being considered. The result may be a hybrid of options A-2 and B. Option A-2 is a modular approach given latitude to substitute for Freedom components. It is virtually identical to A-1 except that it uses Freedom components instead of Bus-1, which is an off-the-shelf Department of Defense Satellite that already is a Shuttle - quality payload capable of providing subsystems such as propulsion, electrical power, guidance, navigation and control, and communication and data management. Option A-2 draws on current space station hardware design and includes a small U. S. Laboratory along with the European and Japanese pressurized modules. It has less truss [three sections (S2, M1, P1) have been deleted] and includes a simplified electrical power system and data management system. Oxygen could be reused with the help of available Russian equipment. The Canadian robotic manipulator has been eliminated. A big problem is clearance between solar arrays when an orbiter docks. Option B is similar to the baseline, i.e., it is based on Freedom components. Section P2 has been deleted from the baseline truss as well as alpha joints and resource nodes. The Option B team based at LaRC saved billions of dollars by reducing the amount of hardware attached outside the pressured modules and simplifying the data management system while sticking essentially with the basic Freedom design. I feel that no matter which design is selected for Freedom, ASCD has played and will play an important role in its final development (including configuration evolution and subsystem growth requirements).

In order to better understand the space-based Earth observing systems, I studies NASA Reference Publication 1009, "An Introduction to Orbit Dynamics and the application to Satellite-Based Earth Monitoring Missions," by David Brooks of LaRC and research the following satellite programs for appropriate information such as purpose, launch vehicle, payload instrumentations, costs, etc.:

1. U.S. Global Change Research Program (USGCRP)
2. Earth Observing System (EOS)
3. Solid Earth Science Missions (SESM)
   a. Magnetic Satellite (MAGSAT)
   b. Laser Geodynamics Satellite (LAGEOS I and II)
   c. Magnetic Field Experiment (MFE/Magnolia)
   d. Application and Research Involving Technologies Observing the Earth's Field from Low Earth Orbiting Satellite (ARISTOTELES)
   e. Gravity and Magnetic Earthprobe Studies (GAMES)
   f. Geomagnetic Observing System (GOS)

Of the missions listed under 3 above, I studied GAMES in the most detail. GAMES is a viable geopotential fields mission to replace ARISTOTELES. It is a high-value, low-cost mission that will have a pegasus launch. It will be equipped with magnetometers like the ones used on the MFE/magnolia mission. Accelerometers will be on the spacecraft to measure drag. It will measure gravity via long wavelength with a GPS receiver and short wavelength with a subsatellite tracker (0.01E gradiometer). Subsatellite performance analysis via the modeling approach has been done at LaRC to define the flight characteristics of the passive aerodynamically stabilized subsatellite and to evaluate its compliance with mission requirements. The analysis conducted to date show that for Mission 1 ("Primary Mission") a passive aerodynamically stabilized, magnetically damped subsatellite meets the feasibility requirement of steady state performance, deployment damping, and orbit lifetime. For Mission 2 ("Extended Mission") deployment damping and orbit lifetime requirements are met; however, the steady state attitude oscillations at 450 km far exceed the +/- 9 degrees requirement.

Two ongoing operational missions I examined were the Upper Atmosphere Research Satellite (UARS) and the Ocean Topography Experiments (TOPEX/Poseidon).

Finally, I investigated the proposed Advanced Research and Development/Small, Expendable Launch Vehicles (AR&D/SELV) Initiative.